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Phosphorus status of soils from the poultry zone in Puerto Rico[1]

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ABSTRACT

The poultry industry is the economic backbone of the south central region of Puerto Rico. However, as in other poultry production regions in the U.S., concern has risen regarding its potentially damaging impact on the environment. Eutrophication of rivers and lakes, induced by excessive nutrient runoff, has forced regulatory agencies to closely evaluate manure disposal practices. Thus, the need is critical for environmentally sound management practices in poultry producing areas. The impact of years of manure applications on the nutritional status of soils was ascertained by evaluating a number of samples from nine poultry farms of Puerto Rico. The farms were selected among those with the highest bird populations. Sixty-seven percent of the samples analyzed contained phosphorus levels (Olsen) in excess of what is considered adequate to support crop growth. Fifty-six percent of these exceeded levels considered by some states as critical for water quality purposes. Measured levels ranged from undetectable values

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up to 900 mg/kg P. A diagnostic tool known as the P index was used in an effort to identify areas of concern. According to this criterion, all farms studied had zones where nutrient runoff could threaten the quality of the surrounding water bodies.

Key words: eutrophication, phosphorus, poultry, manure, Puerto Rico

RESUMEN

Niveles de fósforo en suelos de la región avícola de Puerto Rico

La industria avícola es el bastión económico de la región sur-central de Puerto Rico. Sin embargo, así como en regiones avícolas de los E.E.U.U., ha surgido una gran preocupación sobre el posible impacto de dicha industria en el ambiente. La eutroficación de ríos y lagos a causa de la escorrentía excesiva de nutrimentos en dichos suelos ha forzado a las agencias reguladoras a evaluar las prácticas de disposición de gallinaza empleadas actualmente. Por lo tanto, la implementación de un programa de manejo adecuado es necesario en cada región avícola. El siguiente estudio se realizó con el propósito de evaluar el efecto de años de aplicaciones de gallinaza en el estado nutricional de los suelos. Se tomaron muestras de suelos de nueve fincas avícolas en la región sur-central de la isla. Las fincas se seleccionaron entre aquellas con un número de aves mayor que el promedio en sus municipios. Sesenta y siete porciento de las muestras analizadas tenían niveles de fósforo mayores de lo considerado adecuado para propósitos agrícolas. Cincuenta y seis porciento de las mismas sobrepasaron los límites considerados por algunos estados como críticos para propósitos de calidad de agua. Los valores obtenidos fluctuaron desde no detectables hasta 900 mg/kg P. Se utilizó el índice P (P index) para determinar las áreas que constituyeran un peligro potencial para los cuerpos de agua circundantes. Según dicho criterio todas las fincas estudiadas tenían áreas potencialmente detrimentales a la calidad de agua de dichos cuerpos.

INTRODUCTION

Agricultural nonpoint source (NPS) pollution is considered the major source of stream and lake water contamination in the U.S. (USEPA, 1988). Excessive phosphorus and nitrogen runoff from agricultural lands is often associated with accelerated eutrophication, a condition characterized, among other things, by an increase in aquatic plant growth and the depletion of oxygen from water bodies (Sharpley et al., 1994). Besides preventing the attainment of water quality goals established in the Clean Water Act (USEPA, 1988), this condition represents a major threat to aquatic fauna (Sharpley et al., 1996). Therefore, the implementation of management practices that minimize nutrient runoff must be an essential component of any agricultural enterprise.

A critical element in this effort is the appropriate management of animal manure. Increasing demands for meat products have led to accelerated growth of different animal industries and associated waste production (Moore et al., 1995). Such is the case of the poultry industry. As in a number of states from the mid south region of the U.S., the poultry industry in Puerto Rico has experienced a dramatic boost in the last three decades. Its contribution to the total gross agricultural income has increased from 4% to 14% in the last 40 years (Commonwealth Government of Puerto Rico, Department of Agriculture, 1995). Concurrently, the amount of waste (litter, dead animals) associated with this activity has increased significantly, increasing in turn the difficulties associated with the disposal of these by-products.

Broiler litter is a mixture of manure, bedding material (coffee hulls in the case of Puerto Rico), undigested feed, feathers, and soil picked up during recovery. Because of its low moisture and relatively high nitrogen and phosphorus content, broiler litter is regarded as the most valuable animal manure for fertilizer (Moore et al., 1995). Furthermore, savings in inorganic fertilizer cost and transportation charges are tremendous incentives for on-site utilization of this material to satisfy nutritional demands of crops and pastures. However, these same attributes can turn the material into an ecological hazard. Excessive application to soils can lead to phosphorus runoff into adjacent water bodies, nitrate leaching, and/or can possibly cause elevated bacterial or viral pathogen levels in rivers and lakes (Moore et al., 1995).

Much of the concern regarding eutrophication focuses on phosphorus, which has frequently proven to be the principal factor of accelerated eutrophication (Sharpley et al., 1994). In systems where manure is applied to agricultural lands on the basis of the nitrogen demands of crops, excessive phosphorus buildup generally occurs because manures contain a much lower ratio of N:P than most crops require (Sharpley et al., 1996). Thus the loss of phosphorus in agricultural runoff is a major concern in poultry producing states (Edwards and Daniel, 1992). Since poultry farms in Puerto Rico are located on soils with slopes commonly exceeding 20%, the potential for contamination through runoff and erosion is enormous.

Negative environmental impact notwithstanding, the poultry industry continues to be a dominant economic force in the south central region of the island. In order to reconcile this agricultural activity with the need for a clean environment, an adequate sustainable nutrient management program must be developed and implemented. As a first step towards reaching that goal, this study focused on ascertaining the cumulative impact on soil nutritional status of chicken manure applications, and on identifying those areas and management practices that constitute a hazard to the surrounding water bodies.

MATERIALS AND METHODS

Nine farms from the poultry zone of Puerto Rico were selected to cover both major land resource areas, the humid volcanic uplands

(HVU) and semiarid volcanic uplands (SVU) that constitute this region (Figure 1; Table 1). The farms were chosen to represent those with a higher than average bird population in their municipalities (Table 2),

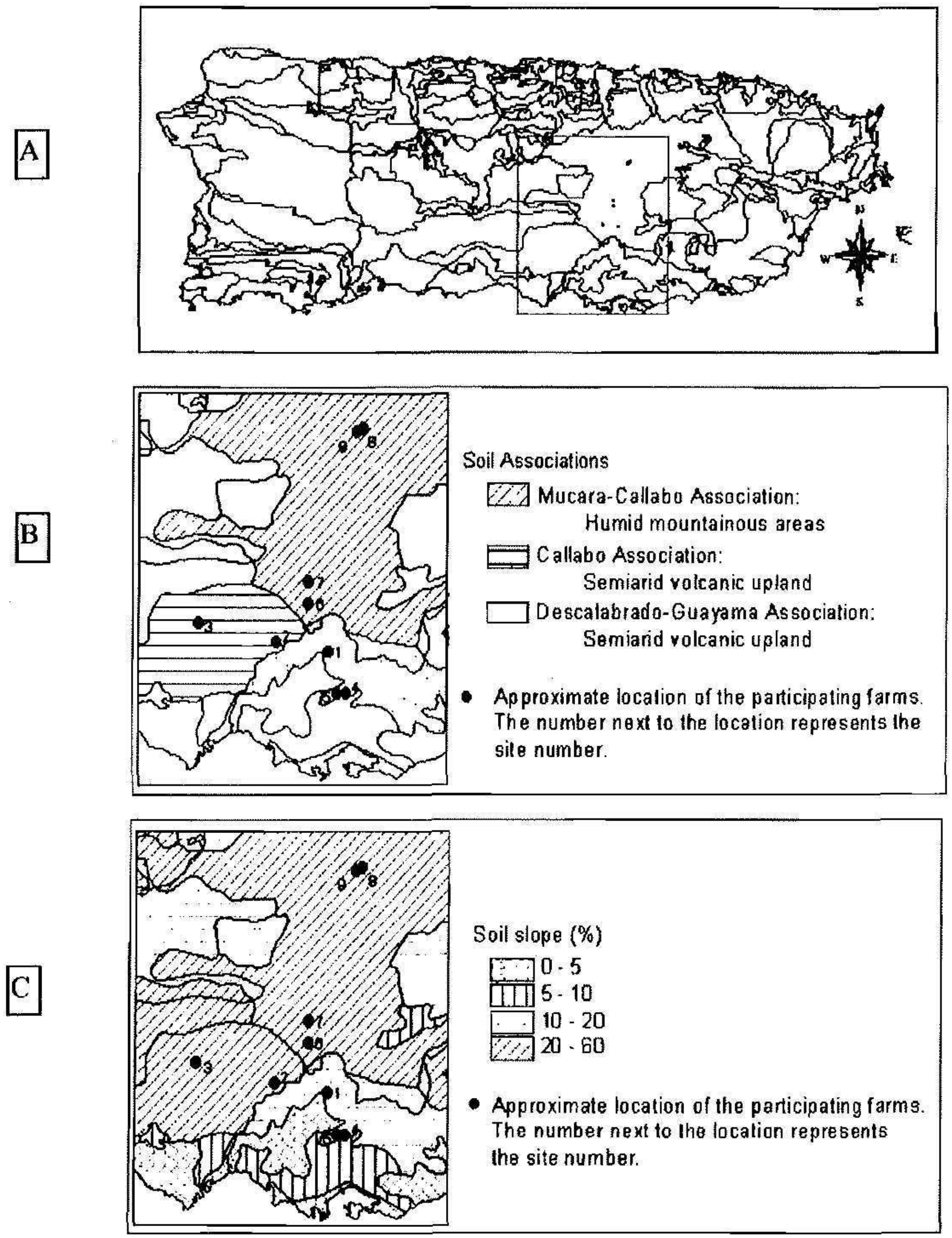

FIGURE 1. A. Location of the poultry zone in Puerto Rico, B. The soil associations and moisture regime of the selected area, and C. Description of the slope of the soils of the area.

TABLE 1.—*Resource characterization of the poultry production area in Puerto Rico.*

Resource Characterization by MLRAs	Volcanic Upland	
	Humid (HVU)	Semiarid (SVU)
Farm I.D. No.	6,7,8,9	1,2,3,4,5
Predominating soil type	Eutropepts, Haplohumults	Ustropepts
Predominating crops	Plantain, Root crops	Pigeon pea, Pumpkin
Temperature range (°C)	20 to 27	20 to 24
Precipitation range (cm^3)	1,147 to 1,638	655 to 983
Soil moisture regime	Udic	Ustic
Soil temperature regime	Isohyperthermic	Isohyperthermic
Average erosion rates[1] (ton/a/yr)	(a) 41 (b) 1	(a) 48 (b) 2
Soil leaching rate[2]	Slow rate	Slow to very slow
Runoff potential[2]	Very rapid	Rapid to very rapid
Slope range (%)	12 to 60	12 to 60

[1]Erosion rates based on RUSLE, (a) cropland and (b) pastureland, estimates from benchmark farming systems evaluated by NRCS, Caribbean Area. The vegetation characteristics of plantains growing in HVU and pigeon peas in SVU were used for estimates in erosion rates.

[2]Soil rating from hydrologic group description and runoff classes as defined in the Soil Survey Manual, USDA, 1993.

and to cover a wide ecosystem spectrum. All farms had been in operation for more than ten years.

Soil samples (first 7.6 cm) were collected in triplicate from at least three different locations within each farm. The sampling sites were chosen to provide an accurate picture of the farms, and were determined on a case by case basis, according to the specific topographical layout of the farms. Air dried samples were ground, sieved (<2 mm), and analyzed for

TABLE 2.—*Average broiler population in municipalities covered in this study (1995).*

Municipality	Avg. no. of broilers per batch per farm[1]
Naranjito	17,233
Coamo	19,066
Aibonito	25,380
Barranquitas	25,418
Salinas	28,455
Comerío	36,846

[1]Data supplied by the statistical division of the Department of Agriculture of Puerto Rico.

pH, electrical conductivity, NH_4OAc exchangeable cations, and organic matter (OM) content (Page et al., 1982). Soil phosphorus was determined by the Olsen method (0.5N $NaHCO_3$). This method was chosen because it is one of the most widely used methods on the island, and because it has consistently proven to be one of the most reliable methods when dealing with samples covering a pH range similar to that which we encountered in this study (i.e., 5.3 to 8.2) (Mallarino, 1995).

Estimates of sheet and rill erosion from each site were obtained by applying the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1996). Information on climate, soil erodibility, percentage slope, slope length, hydrologic soil group, type and quantity of vegetative cover at the site, and soil conservation practices was gathered on the initial visit to each farm. Other parameters (e.g., P fertilizer application rate, P fertilizer application method) were obtained by interviewing the farm owners.

P index:

Recently a group of scientists sponsored by USDA developed a tool referred to as the Phosphorus (P) index to identify critical areas or management practices that can lead to unfavorable impact on water bodies due to phosphorus movement (Lemunyon and Gilbert, 1993). Given that phosphorus contamination usually results from a combination of factors, this concept takes into account a number of soil and management practices to estimate the extent of potential phosphorus losses from a field. These factors are soil erosion, irrigation erosion, runoff, soil P test levels, P fertilizer application rate and method, organic P, application rate, and organic P application method. On the basis of the relative contribution of each of these parameters, an overall rating which classifies its vulnerability to phosphorus losses is assigned to a specific site. Although it is still in the developing stage and requires local adaptation, this tool has shown great promise for identifying potentially sensitive areas, a key element in efforts towards establishing an environmentally sound waste management program (Stevens et al., 1993). We used this tool to evaluate our results.

RESULTS AND DISCUSSION

From an agronomic standpoint, Olsen available phosphorus (P) levels in the 10 to 15 mg/kg range delineate what is considered a critical range (Sharpley et al., 1996). In other words, that is the break-point between a medium soil test value, where crop response to fertilizer is likely, and a high soil test value where further P additions do not render benefits in crop performance. Sixty-seven percent (67%) of the samples analyzed in our study had soil test phosphorus (STP) levels that exceeded 25 mg/kg (Figure 2). These results are in accord with reports from poultry production regions in the U.S. where inadequate poultry litter management practices have resulted in phosphorus buildups that are well beyond agronomic functional values (Daniel et al., 1994; Moore et al., 1995; Sharpley et al., 1996).

Increase in STP beyond agronomic critical values does not necessarily imply that the quality of the surrounding water bodies has been compromised. In fact, soil tests alone cannot accurately predict the amount of phosphorus lost from an individual field or watershed. Also involved is the influence of other highly variable factors (such as climate, topography, and vegetation) on runoff volume and composition. However, soils with extremely high STP levels have been found to be more at risk to phosphorus loss in runoff and thus require more careful management (Sharpley et al., 1996). The phosphorus enriching potential of broiler litter can be dramatic (Table 3), with consequences that can be extremely deleterious to the surrounding water bodies (Sims, 1993; Daniel et al., 1994). Thus the establishment of a sound management program is imperative in order to reconcile this agricultural activity with a clean environment.

The relationship between STP and increased phosphorus [dissolved (DP) or particulate (PP)] in runoff has led several states to establish an "environmentally critical STP." These values represent limits beyond

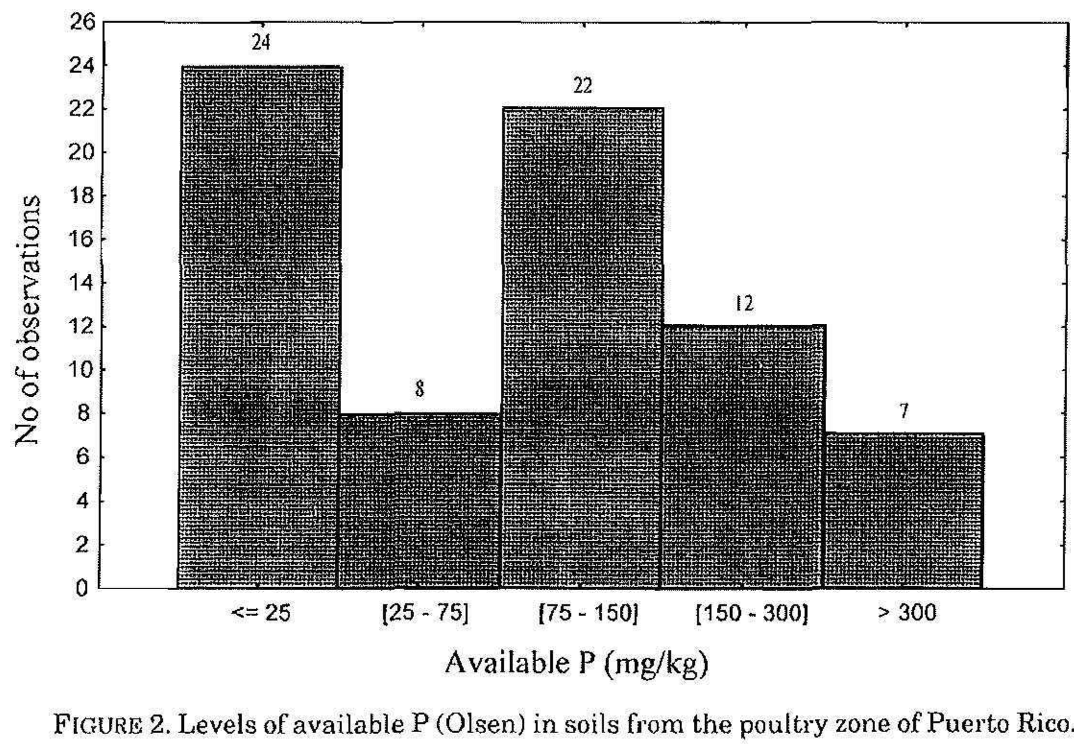

FIGURE 2. Levels of available P (Olsen) in soils from the poultry zone of Puerto Rico.

TABLE 3.—*Nutritional enrichment of Puerto Rican soils (7.5 cm depth) from chicken manure applications: Available P (Olsen) mg/kg soil.*

	Farm no. 2	Farm no. 3	Farm no. 8	Farm no. 9
Untreated soil	3.49	11.25	0.72	3.21
Treated soil[1]	94.07	55.56	117.17	188.80
Treated soil[1]	267.56	123.71	453.19	500.30

[1]These soils had received undetermined quantities of chicken manure for a number of years.

which runoff may contain enough phosphorus to promote eutrophication. Generally these values are three to ten times higher than their agronomic counterparts. Although estimates vary from state to state (Sharpley et al., 1996), we have chosen 75 mg/kg phosphorus (Olsen) as a conservative cutoff value for comparative purposes. Fifty-six percent (56%) of the samples analyzed in our study met or exceeded that limit, a finding which attests to the inefficacy of local disposal regulations in preventing or detecting potential zones of non point phosphorus contamination.

On the regulation end, the USEPA is currently contemplating limiting the concentration of dissolved phosphorus DP in agricultural runoff to 1,000 (g/L, a value presently applied to sewage sludge treatment plants (Sharpley et al., 1996). Pote et al. (1996) estimated that soils having 200 mg/kg of phosphorus (Mehlich-3) in the top 2 cm would produce such a DP concentration in their runoff. If we consider that the Mehlich-3 method usually extracts 1.5 to 2 times more P than Bray-1 or Olsen (Sharpley et al., 1994), we can establish a value of 130 mg/kg as indicative of soils exceeding the 1,000 (g/L DP limit. Thirty-six percent (36%) of the samples analyzed in our study exceeded that limit. In fact, the average available P obtained in this study, 137 mg/kg, exceeds the above mentioned value, all of which again points out the need to establish a better manure management system in Puerto Rico. We must recognize that the farms selected in this study corresponded to those with a higher than average bird population in their respective municipalities. Thus the values reported may not be representative of the whole poultry producing population. However, we consider the results to be alarming enough to warrant a thorough assessment of the nutritional status and water contaminant potential of the soils in this region. Once the amount of P in soil exceeds agronomic values, its restoration down to adequate levels could take several years or even decades. For instance, McCollum (1991) estimated that without further additions of P, eight to ten years of cropping corn (*Zea mays L.*) would be required to decrease P levels in a sandy soil from 30 to 15 mg/kg (Olsen). Thus we must concentrate our efforts towards preventing excessive phosphorus loading in agricultural soils.

Comparison within farms:

Table 4 shows average phosphorus levels of the individual plots sampled. Plots not sampled in triplicate were excluded from this analysis. Only three farms (2, 3, and 8) had zones that differed significantly among themselves in their phosphorus levels. This finding could give the impression that most farmers employ a uniform litter application system, thereby distributing nutrient loads uniformly across their farms. A closer look at the data, however, reveals another picture. In some cases, farms 1, 4, and 9, the average phosphorus levels obtained for different plots differed widely; however, the high standard deviation associated with the values precludes said difference from being statis-

TABLE 4.—*Within farm comparison: available P levels.*

Farm I.D. number	Average P on Plot (mg/kg)	Standard Deviation	LSD test (95% confidence level)[1]
1	332.46	382.14	A
1	143.03	29.59	A
2	44.03	43.69	A
2	265.33	3.15	B
2	61.20	112.83	A
3	101.92	21.47	A
3	14.02	3.08	B
4	173.46	104.96	A
4	36.64	15.28	A
5	58.06	69.84	A
5	69.23	8.65	A
5	9.12	1.39	A
6	162.29	22.78	A
6	179.63	83.53	A
7	44.39	41.31	A
7	90.69	16.43	A
7	33.20	57.51	A
8	534.44	195.90	A
8	64.75	45.51	B
8	0.76	0.77	B
9	6.07	2.57	A
9	570.17	388.84	A

[1]Samples with same letters were not significantly different.

tically significant. There are also sites exhibiting a relatively low average in available phosphorus but an exceedingly large standard deviation (e.g., farm 2). This finding suggests a common but dangerous trend in poultry litter management where small areas that are closer to the ranch are frequently overloaded with litter to minimize transportation and manual labor costs (Moore et al., 1995). Such trends were confirmed visually on a sampling visit.

Comparison among farms:

Significant differences occurred only among farms with P levels at both ends of the spectrum, that is, those with the highest average value (9) and those at the lower end (3, 5, and 7) (Table 5). Similarly to the previous case, the large standard deviation associated with the values prevented a higher degree of stratification. It is important to notice that the average phosphorus concentration on all farms exceeds three times the previously cited agronomic critical value. No significant differences were observed between farms located in the HVU and those in the SVU regions (data not shown).

Correlation between available P levels and other soil parameters

Poultry litter is regarded as the most valuable fertilizer among all animal manures, mainly because of its relatively low water content (Moore et al., 1995; Daniel et al., 1994; Sharpley et al., 1994). Poultry litter contributes large quantities of N, P, and K, some Ca, Mg, and S, and trace elements (e.g., Cu, Zn). In some cases poultry litter also increases the soil organic matter reserve, consequently improving

TABLE 5.—*Among farms comparison: available P (Olsen).*

Farm I.D. number	n	Average P on Plot (mg/kg)	Standard Deviation	LSD test (95% confidence level)[1]
1	6	237.75	263.69	AB
2	9	100.84	118.38	AB
3	6	57.97	50.06	B
4	6	105.05	100.57	AB
5	9	45.47	44.78	B
6	6	170.96	55.58	AB
7	9	56.09	44.92	B
8	9	199.98	271.66	AB
9	6	288.12	394.89	A

[1]Samples with same letters were not significantly different.

properties such as cation exchange capacity (CEC), tilth, water holding capacity, and structural stability. Since a strong correlation exists between poultry manure applications and available phosphorus concentration in soils, the relation between this parameter and some of the above mentioned properties was examined (through correlation analyses) to ascertain the impact of long term poultry litter applications in some of our soils. As expected, a strong positive correlation was observed between the concentration of available phosphorus and the amount of exchangeable potassium (K) in the soils (Table 6; Figure 3). Poultry litter contains approximately 2% K, and thus can be an important source of this element (Daniel et al., 1994; Muñoz et al., 1990). In fact, excessive potassium inputs from poultry litter have in some cases resulted in grass tetany, a ruminant condition caused by a nutritional imbalance (K/ (Ca + Mg) in forage (Wilkinson, 1979).

A positive correlation was also observed between available P, electrical conductivity, and exchangeable Na (Table 6). These results coincide with observations made by others and reflect the impact that salts (e.g., NaCl) in the broilers' feedstock may have on soils (Moore et al., 1995; Wilkinson, 1979). This effect could be a problem in areas where evapotranspiration rates exceed rainfall; however, there is little evidence of salinity problems in soils where agronomic rates of poultry litter have been applied. The correlation between organic matter content and P and between exchangeable Mg and P, although somewhat weak, still reflected a positive trend. On the other hand, there was no

TABLE 6.—*Correlation results between available P and other soil chemical parameters.*

Chemical parameter	n[1]	Correlation coefficient, *r*	Empirical relation between parameters
Exch. K (cmol$^+$/kg soil)	64	0.69	Exch K = 0.975 + 0.0081 (Olsen P)
Exch. Na (cmol$^+$/kg soil)	60	0.74	Exch Na = 0.48 + 0.0015 (Olsen P)
Exch. Ca (cmol$^+$/kg soil)	64	-0.14	Exch Ca = 20.61 - 0.0074 (Olsen P)
Exch. Mg (cmol$^+$/kg soil)	64	0.54	Exch Mg = 5.26 + 0.0117 (Olsen P)
Organic Matter (%)	64	0.56	%OM = 2.64 + 0.0065 (Olsen P)
Electrical Conductivity (dS/m)	72	0.73	EC = 0.59 + 0.0047 (Olsen P)
Exch. [K/(Ca +Mg)]	64	0.51	[K/(Ca +Mg)] = 0.068 + 0.0002 (Olsen P)

[1]Number of observations differ because complete results were not available in all cases.

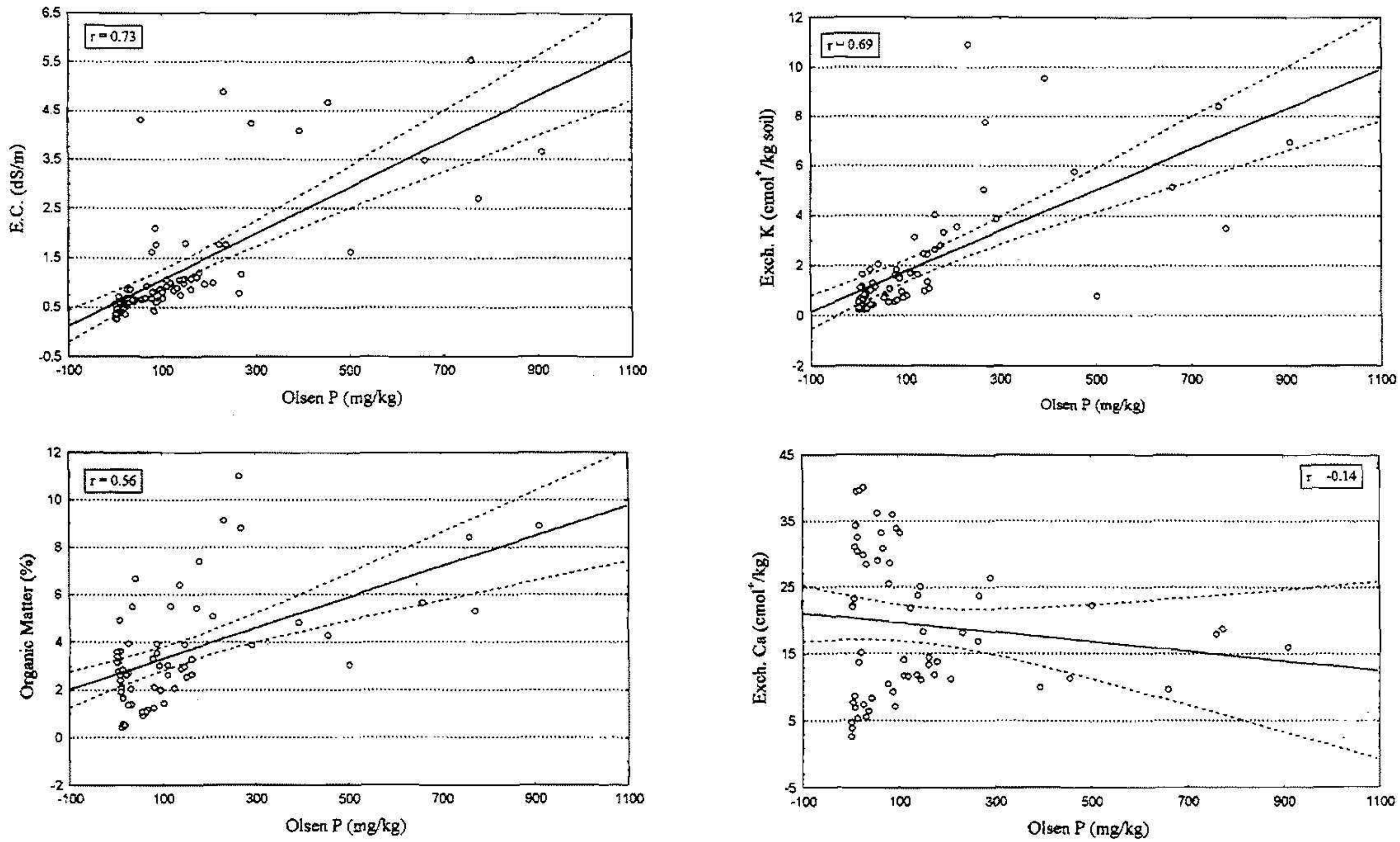

FIGURE 3. Correlation between available P levels and different soil chemical parameters.

relation between levels of exchangeable Ca and P. This finding indicates that Ca levels in poultry litter were much lower than the background Ca levels of these soils, and thus poultry litter applications would not result in a significant input of this element.

P Index:

The phosphorus index was recently proposed as a means of identifying areas or management practices unfavorable to water bodies through excessive P movement (Lemunyon et al., 1993). At present, the P index is an 8 (site characteristic) by 5 (phosphorus loss rating level) matrix where different parameters of known relevance to P behavior in soils are considered (Table 7). The eight site parameters are those mentioned in the materials and method section. The five P loss levels are *none, low, medium, high, and very high*. On the basis of the particular characteristics of the site being evaluated, a weighing factor is assigned to each of those parameters (Table 7). An overall rating, which classifies its vulnerability to excessive P losses, is then assigned to each site. A higher score indicates a higher potential for significant P movement from the site. Through this exercise those parameters accelerating eutrophication may become apparent, suggesting the need of a series of conservation practices (e.g., buffer strips, contour tillage, residue management systems, hillside ditches) or corrective management measures to improve the status of those areas.

The results obtained with the P index are presented with the sole purpose of introducing its rationale and not as a detailed evaluation of its effectiveness. Local research is needed to validate this tool and to modify it to suit our purposes.

Our P index estimates once again suggest a potential eutrophication crisis in Puerto Rico. Sites of High or Very High vulnerability were detected on all nine farms (Table 8). This exercise showed that significant improvement could be made by changing the application method (incorporation rather than surface application), and by reducing soil erosion. However, for some of these soils the best alternative would be to discontinue P applications until appropriate levels are attained. This would of course require a serious commitment between the government and the poultry industry to identify all sensitive areas requiring special attention and to monitor the impact of the remedial strategies implemented.

Traditionally, poultry litter disposal guidelines in Puerto Rico have lacked the scientific foundation necessary for them to be effective. In some cases, farmers have been advised to dispose of their manure as a "thin layer" on the soil surface. This method leaves to the farmer's dis-

TABLE 7.—*Phosphorus Index, version 1.0, adapted from Lemunyon and Gilbert, 1993.*

Site characteristic (weight)	Phosphorus loss rating (Value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Soil erosion (1.5)	NA	< 11.2 Mg/ha	11.2 to 22.4 Mg/ha	22.4 to 33.6 Mg/ha	> 33.6 Mg/ha
Irrigation erosion (1.5)	NA	QS[1] < 6 for very erodible soils, <10 for others	QS > 10 for resistant soils	QS > 10 for erodible soils	QS > 6 for very erodible soils
Runoff class (0.5)	Negligible	Very low or low	Medium	High	Very high
Soil P test (1.0)	NA	Low	Medium	High	Excessive
P fertilizer application rate (0.75)	None applied	1.12 to 33.6 kg P_2O_5 /ha	34.7 to 101 kg P_2O_5 /ha	102 to 168 kg P_2O_5/ha	> 168 kg P_2O_5/ha
P fertilizer application method (0.5)	None applied	Placed deeper than 5.08 cm.	Incorporated immediately before crop	Incorp. > 3 mo before crop	Surface applied > 3 mo before crop
Organic P source application rate (1.0)	None applied	1.12 to 33.6 kg P_2O_5 /ha	34.7 to 67.2 kg P_2O_5 /ha	68.3 to 101 kg P_2O_5/ha	> 101 kg P_2O_5/ha
Organic P source application method (1.0)	None	Injected deeper than 5.08 cm.	Incorporated immediately before crop	Incorp. > 3 mo before crop	Surface applied

[1]Product of the introduced flow rate (Q) and furrow slope (S).

TABLE 8.—*P index values and site vulnerability for different farms of the poultry zone in Puerto Rico.*

Farm I.D. no.	P Index Value	Site Vulnerability Rating[1]	P Index Value[3]
1	29	High	13
2	32	High	16
3	15	High	6
4	20	High	8
5	16	High	7
6	40	Very High	24
7	34	Very High	18
8[2]	9	Medium	8
8	29.5	High	13.5
9	31	High	15

[1]Corresponding ranges of P Index values for site vulnerability: < 8 (low), 8 to 14 (medium), 15 to 32 (high), > 32 (very high), (adapted from Lemunyon and Gilbert, 1993).

[2]This site has never received manure applications.

[3]Value obtained if P applications are discontinued at the site.

cretion the appropriate loading rates of a "thin layer" and obviates critical factors such as soil type, topography, amount of manure to be disposed of, and farm size. In other cases, disposal guidelines have been established on the basis of nitrogen requirements of crops. However, this practice ultimately results in P buildups well beyond critical agronomic values because manures typically have a much lower N:P ratio ($\cong$ 3:1) than most crops require ($\cong$ 9:1).

A comprehensive approach is needed to develop poultry litter management guidelines that are both agronomically and environmentally sound. Such an initiative should come from the agricultural sector, which recognizes the intricacies of this enterprise. A task force involving the Poultry Industry, the Department of Agriculture, the College of Agricultural Sciences, and other relevant agricultural agencies (e.g., Natural Resources Conservation Service) should be instituted to address an issue that could well determine the fate of the poultry industry in Puerto Rico.

CONCLUSIONS

A survey of the nutritional status of soils from the poultry zone of Puerto Rico revealed a widespread threat to water quality by excessive phosphorus levels. Sixty-seven percent of the samples analyzed showed available P (Olsen) levels beyond those considered adequate for crop growth. Fifty-six percent of these exceeded a proposed environmental critical P level; thus the amount of P in runoff may be conducive to eutrophication. A highly significant correlation was observed between the amount of P and levels of soil exchangeable K^+, and Na^+, as well as with the soil's electrical conductivity. A positive correlation was also found between the levels of P and the amount of organic matter, all of which evidences years of poultry litter applications on these soils.

The P index was used in an attempt to identify those areas and management practices which lead to excessive P runoff. All farms sampled had zones that ranked high or very high in terms of their eutrophication potential. A broader soil nutritional census is needed to identify those areas where litter applications must be discontinued. An adequate nutrient management program that incorporates a number of soil conservation practices must be instituted in those areas still capable of benefiting from poultry litter applications. Research is needed to develop adequate methodology that can relate STP to bio-available P in streams, and to further advance our knowledge on the mechanisms controlling phosphorus dynamics in our soils. Research is also needed to validate the P index locally and to evaluate alternate litter management practices (e.g., cattle feed, biogas production, composting). The poultry industry is keystone to the economic well being of the south central region of Puerto Rico; and thus its stability must be promoted by reconciling its existence with a clean environment.

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